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Abnormalities of foot and ankle alignment in individuals with chronic ankle instability: a systematic review

Takumi Kobayashi^{1*}, Yuta Koshino² and Takahiro Miki³

Abstract

Background: To prevent recurrent ankle sprain, it is important to clarify the pathology of chronic ankle instability (CAI). An association has been reported between CAI and abnormalities of foot posture and ankle alignment. There is no consensus on the types of these abnormalities that occur in individuals with CAI. The objective of this systematic review is to clarify the relevance of abnormality of foot posture and ankle alignment for CAI.

Methods: A systematic computerized literature search was performed of the PubMed, CINAHL, SPORTDiscus, Web of Science, and the Cochrane Register of Clinical Trials databases. The selected studies either compared CAI patients with a control group or CAI ankles with contralateral healthy ankles and specifically reported foot posture and alignment of the ankle in the outcomes. They were written in English and published prior to June 2021. The methodological quality of the included studies was evaluated using a 16-question index. Data were extracted independently by two reviewers, and the certainty of evidence was assessed using GRADE approach.

Results: Sixteen studies including 872 patients of high to low methodological quality were included. These showed there was significant anterior displacement and internal rotation of the talus in CAI ankles (low evidence), but there was no consensus on fibular alignment or foot posture.

Conclusions: This review showed there was significant anterior displacement and internal rotation of the talus in CAI ankles but found no consensus on the characteristics of fibular and foot alignment. Further investigations are required to clarify the characteristic foot and ankle malalignment in CAI to facilitate the development of efficient interventions.

Keywords: Ankle instability, Foot posture, Talus, Fibula

Background

Ankle sprain is one of the most common ankle injuries, with a recurrence rate exceeding 50% [1]. Ankle sprains cause mechanical and functional disorders of the ankle joint, and repeated ankle sprains can result in chronic ankle instability (CAI). The main symptoms of CAI are the ankle "giving way", perceived ankle instability,

and further recurrence of ankle sprain [2]. In addition, CAI associated with repeated ankle sprain leads to an increased risk of future ankle osteoarthritis [1]. Recurrent ankle sprains are associated with dysfunction such as limited range of ankle dorsiflexion, decreased external muscle strength, and static and dynamic postural stability deficit [1]. Furthermore, CAI is associated with a decrease in health-related quality of life [3], so clarifying the pathology of CAI is important for developing interventions that can prevent recurrent ankle sprain.

Individuals with CAI experience repeated ankle sprains caused by various dysfunctions, such as pathologic laxity, neuromuscular inhibition, balance deficit, and muscle

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^{*}Correspondence: kobatakku@chitose-reha.ac.jp

¹ Department of Rehabilitation, Faculty of Health Science, Hokkaido Chitose College of Rehabilitation, 2-10 Satomi, Chitose, Hokkaido 066-0055, Japan

weakness, including arthrokinematic restrictions caused by abnormal foot and ankle joint alignment such as talar anterior displacement or cavus foot deformity [4]. Abnormal anterior displacement or internal rotation of talus can affect the talar cartilage strain and contribute to the development of osteoarthritis in the future [5, 6]. Abnormalities of foot posture, such as pes planus, have also been noted to potentially alter lower limb kinematics, including increase rearfoot eversion or tibial internal rotation during running, and may thus increase the risk of medial tibial stress syndrome or patellofemoral pain [7]. Abnormalities associated with CAI thus need to be addressed to mitigate long-term consequences.

Rearfoot varus has been reported as a risk factor for CAI [8], and is considered to contribute to biomechanical changes such as increased ankle inversion and lateral deviation of COP during dynamic tasks [9, 10]. In addition, increased navicular drop [11] and posterior deviation of the fibula [12] have been reported as potential risk factors for ankle sprain, although the results have been inconsistent among individuals with CAI [13-16]. Furthermore, the anterior talofibular ligament injury contributes to changes in cartilage loading in the ankle joint by altering talar alignment [5, 6]. For these various abnormalities of foot and ankle alignment, conservative interventions such as joint mobilization or taping to address ankle realignment improved the ankle dorsiflexion range of motion or dynamic postural stability of individuals with CAI [17, 18]. In addition, the surgical repair or reconstruction of the lateral ankle ligament was performed to prevent future osteoarthritis of the ankle [19]. Furthermore, insoles are used for abnormalities of foot posture such as pes planus or cavus foot deformity [20, 21]. However, no consensus has been reached on the types of abnormality of foot posture and ankle alignment that occur with CAI. Although understanding these abnormalities could contribute to the development of more efficient conservative treatments, and ligament repair or reconstruction for CAI, no systematic reviews have clarified the relationship between abnormalities of foot and ankle alignment and CAI. The objective of this systematic review was to clarify the relevance of abnormalities of foot posture and ankle alignment for CAI.

Methods

Literature search

This study was conducted and reported according to the PRISMA guidelines for reporting systematic reviews and meta-analysis [22]. A computerized literature search of the PubMed, CINAHL, SPORTDiscus, Web of Science, and the Cochrane Register of Clinical Trials databases was performed on December 6, 2019 and repeated June 15, 2021, and included articles published any time up

to that date. The search strategies for each database are shown in Additional file 1: Table A.1-A.4. Articles identified from the search were stored and managed using Endnote X9.

Inclusion and exclusion criteria

The inclusion criteria were as follows: eligible articles had to be full-text reports of a randomized control trial, cohort study, cross-sectional study, case-control study, or case series published in a peer-reviewed journal; the study compared a group of human participants with CAI with a control group or compared a healthy leg with the contralateral leg with CAI; foot posture and static alignment of the ankle were included in the outcome; and the article was written in English. Because this study included the search period before the publication of recommended criteria by the International Ankle Consortium [2], we also included studies that defined CAI based on a history of ankle sprain, perceived ankle instability, or imaging findings, as well as articles that did not specify the coper subjects. Articles were excluded if the numbers of participants in the CAI and control groups were not clearly presented or quantitative data were not reported for both groups.

Literature screening

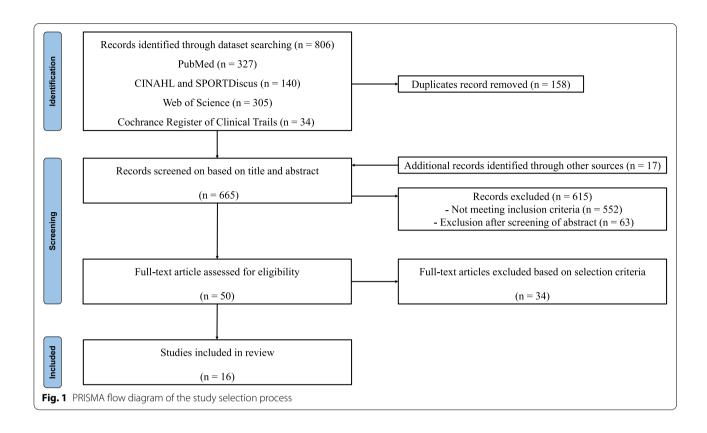
After the initial search, articles duplicated between the databases were removed. The titles and abstracts were assessed for relevance to the aim of the review, and the full-text articles were retrieved for those identified as relevant. These were screened against the inclusion and exclusion criteria, and the reference lists of the articles were cross-checked for additional articles. Two reviewers independently screened all the articles identified in the database search, with any disagreements discussed at a meeting between the two reviewers and resolved by consensus. If no consensus was achieved for a specific item, a third reviewer was involved to achieve a consensus between the two raters (Fig. 1).

Data extraction

All alignment outcome measures, measurements of foot posture and static alignment of the ankle were extracted from the included articles by two independent reviewers. Information about participants, study objectives, definitions of CAI, independent and dependent variables, measurement methods, statistical analyses, main findings, and conclusions were also collected.

Quality and certainty assessment

Two independent reviewers assessed the risk of bias, with a third reviewer deciding in cases where consensus



was lacking. The included studies were evaluated for quality based on an index (Downs and Blacks criteria checklist) developed for nonrandomized studies [23]. Because the present systematic review did not apply questions relating to methodological design validity associated with an intervention, this study used a 16-question version adapted from the original index by Munn et al. (Additional file 1: Table B.1) [24]. The maximum possible score was 17, and the authors recommended that studies scoring < 60% should be considered of low quality, those scoring 60%-74% of moderate quality, and those scoring > 75% of high quality [24]. The independent critical appraisal and data extraction were completed by two reviewers. Any disagreements were resolved by discussion to reach a consensus. Results of the study bias and quality assessment were considered as a component of the outcome certainty assessment. Two independent reviewers assessed the certainty of evidence as "high", "moderate", "low", or "very low" using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach [25]. As per the GRADE approach, certainty levels for observational studies started at the "low-certainty" evidence classification level and were upgraded or downgraded according to the set criteria.

Results

Study selection and quality

The results of the literature search and review process are presented in Fig. 1. Sixteen papers provided results that were included in the analysis (Table 1) [6, 8, 13–16, 26–35]. The methodological quality scores of the included studies ranged from 6 (35.3%) to 13 (76.5%), with a mean score of 9.69 (57.0%) (Table 2). One study was considered to be of high methodological quality, 5 studies were of moderate quality, and 11 studies were of poor quality.

Fibula alignment

Six studies including 239 patients (39.8 patients per study) investigated fibular alignment [13–16, 28, 35]. Methodological quality was low except for one paper showing moderate quality. Two of these studies recruited patients with CAI who were undergoing lateral ligament reconstruction surgery (only preoperative values were included as results) [13, 16], and the other four studies were based on functional disability, such as recurrent ankle sprains or subjective instability [14, 15, 28, 35]. Two of the papers measured fibular alignment using two-dimensional (2D) analysis in the axial plane based on computed tomography (CT) or magnetic resonance imaging (MRI) images to calculate the axial malleolar index (AMI) [13, 16], three papers used 2D analysis based

Table 1 Details of the included studies

	Study		Study design	Subjects	Definition of CAI	Dutomo	Main findings	Coedusions
Fibula alignment	Berkowitz 2004 13	To determine whether there were significant differences in fibular position in a population of patients who underwent lateral ankle stabilization procedures.	Caso-control study	Instability group: 84 (52 mm, 13 women) control group: 65 (52 mm, 13 women)	Undergoing lateral ankle ligament recommendon.	AML	The mean (SD) AMI was 17° (6°) in the CAI group and 9° (6°) in the central group.	The fibrilar position was significantly more posterior in the CAI group compared to the central group $(P<0.01),$
	Hubbard 2006 14	To assess the position of the distal fibrilla in individuals with CAL	Caso-control study	CA1 group: 30 (15 mm, 15 women) omtrol group: 30 (15 mm, 15 women)	Original criteris based on previous ankle sprain and functional disability (a previous history of unilateral midde sprain, antice currently giving way, pair, forlings of insutellity, and decreased functions).	Fibelar alignment (the distance from the auterior margin of the distal tibia to the unterior margin of the distal fibela).	The main (SD) values of the fibriler position were $14.3 (3.1)$ mm in the CAI askin, $16.3 (3.4)$ mm in the caposite addes of the CAI group, $16.3 (4.6)$ mm in the satisfied addes of the central group, and $16.7 (3.3)$ mm in the apposite addes of the central group, and $16.7 (3.3)$ mm in the apposite addes of the central group.	The fibelar position was significantly more unterior in the CAI axides compared in the oppose to axides of the CAI group ($P=0.006$) and the matched axides of the contrast group ($P=0.045$).
Talax goodiscing	Hubbard 2007 ²⁸	To cusmine differences between subjects with and without unilateral CAI and to identify which of these were most closely associated with CAI.	Casa-control study	CA1 group: 30 (15 mm, 15 women) control group: 30 (15 mm, 15 women)	Original criteris based on provious ankle spents and functional disability (a previous bistory of unifarmed audio spents, and/o currently giving way, pain, feelings of instability, and decreased Suscious).	Fibilar alignment (the distance from the anterior margin of the distal this to the anterior margin of the distal fibilal, and a locity, take hyperselvity, static balance, dynamic balance, sakke strength, big strength, lower extensity multilgaments, and the ability.	The mean (SD) values of the fitnine position were $14.9 (1.8)$ mm in the CAI stables, $17.1 (1.7)$ mm in the opposite addles of the CAI group, $16.0 (4.6)$ mm in the matched stable of the control group, and $16.7 (1.3)$ mm in the opposite articles of the control group.	No significant difference between the ankles (group by side: $P=0.087;$ group: $P=0.01;$ side: $P=41i.$
	Kohuyushi 2014 ¹³	To determine whether there was absormal fibralar alignment in individuals with CAL	Case series	Unilateral CAI patients: 17 men	Original orderis based on provious stakle sprain and functional disability (a precion bisoty of multiple unitated at the sprain, multiple unitated opioides of the axise giving way, scalanted addle instability, and functional performance (mb).	Fibralar alignmen (the ameropositive and recifolium) positional difference of the distal 10 on of the Shala.	The mean (SD) assuring translation increased from 0.04 (0.92) to 0.58 (1.73) run is CA1 askinc conquired to healthy acidist. The mean (SD) insuring translation increased from 0.57 (0.81) to 0.68 (1.15) run in CA1 askinc conquired to healthy arisins.	The position of the datal fibrals was significantly more lateral in CAI antice thus in healthy antices ($P < 0.65$).
	Li 2017 ³⁶	To evaluate fibular and takes positions in subjects with recolarical anale instability.	Cass=control study	CAI group: 54 (41 mm, 13 women) control group: 51 (36 mm, 15 women)	Original criteria based on provious make upon and mechanical insubélity. (a precises bisney of wake opens, percision symptoms of wake isosability, and a positive finding in the arterior drawne test).	AMI and innormalisedur indus.	The mean (SD) of the AMI was 11.00° (5.62°) in the CAI group and 1.80° (4.41° in the costes) group. The mean (SD) of the internalicular index was 9.97° (4.48°) in the CAI group and 9.33° (4.50°) in the cost of group.	The AMI was significantly genere in the CAI group than in the control group $(P < 601)$. No significant difference in the internalized rinder between the groups $(P < 0.05)$.
	Wilestrem 2010b ³³	To evaluate the correlation between dynamic poweral control and mechanical ankle with the power among patients with and without chronic ankle instability and controls.	Case-control study	CA1 group: 24 (12 non., 12 ivenses) open group: 24 (12 non., 12 venses) control group: 24 (12 non., 12 venses)	Original criteris based on previous ankle spans and finational disability (a previous bistory of craintent lateral nakle spans and giving very of the ankle; and lateral nakle spans shown and key mate between 3 and formethe below subset participation as access 220 on the Arabid John Functional Associators Test; reported pain, instability, and for wandarses in the irreduced arkin; failure to resource all artivities at the pro-inspire ylevel.	Fibility alignment (the distance from the asterior rangin of the distal thin the asterior rangin of the distal fibility, while just selffness, and dynamic posture control.	The mean (SD) of the filtedar position was $12.8(4.2)$ mm in the CA1 group, 12.4 (3.9) mm in the coper group, and 12.2 (3.3) mm in the country group.	No significant difference between the groups (P $\sim 0.819)$
	Caputo 2009 ¹	To quantify the effects of lateral unide insulability on the motion of the ubiotalar joint under weight bearing loading.	Case series	Nice unitarial CAI guilents (5 mes, 4 women)	Undergoing lateral sakke ligament recommenders.	Tiblotalar joint kinematics.	The mean (SD) sourcier and susperior translations were grown by 0.9 (0.5) run and 0.2 (0.2) run in the CAI addiso compared to the interestables. The secon (SD) interests studies was greater by 5.3° (1.6°) in the CAI enklos compared to the intert addiso.	Compared to the contradictual into tankles, the CAI makks were significantly more assures ($P=0.035$) with a slight superior translation ($P=0.02$), and general translation ($P=0.02$).
	Magerkurth 2010 32	To reasoure consecus characteristics in the flowed and lateral plane.	Case—control study	CA1 group: 52 (18 mm, 34 women) control group: 52 (18 mm, 34 women)	Original erderin based on previous entale spanis and functional disobility (a previous history of multiple utilities) and synamous and synamous in multi-lay requiring augical Hyarmet reconstruction).	Proceed plane: depth of the take curvature; latend and model multicolar lengths. Latend plane: position of the take control relations relative to the anatomical axis or the effect (TDCOR), the taked latend surface angle.	The mean (SD) TRCOR was 2.5 (1.6) rum in the CA1 group and 1.6 (2.2) run in the extent group.	The TECOR was eignificantly more asserted in the CA1 group than in the control group (P $<0.051,$
	Li 2017 36	To evaluate fibeliar and takes positions in subjects with mechanical ankle instability.	Case-control study	CA1 group: 54 (41 mm, 13 women) control group: 51 (36 mm, 15 women)	Original criterio bosed on previous stable sprain and mechanical instability (a previous bistory of analosymens, persistent symptoms of analos modelsby, and a positive finding in the artestor drawner test).	Malfeolar tako indes.	The mean (SD) of the mulleolar rules index was 89.65° (3.77°) in the CA1 group and 85.79° (4.40°) in the coursel group.	The talks oddfished grouter instruction relation (eigenflowerly greater realisolar talks index) in the CAI group than in the centred group ($P < 0.81$).
	Wikstrom 2010a 34	To desermine whether the negital plane position of the takes differs between uninjured controls and individuals with CAL	Casa-control study	CAI group; 24 (12 men. 12 weenen) control group; 24 (12 men. 12 weenen)	Original criterio based cor provisors stakls openia and frantiscual disability (sprevisor bishey of criticand bland ankle openia and giving way of the ankle, to provisor bishey of criticand bland and to provisor bishey of critical bland and to control before body practical post practical and an openia before body practical post an access 220 on the Ankle from Franciscual Associators Text reported pairs, instability, and the vanishous in the brooked making failure to recurse all architects at the pro-injusy levels.		The non-(SD) of signific place take position was in 3.1(1.4) run in the CAI stakes, 3.9 (1.6) run in the enter-tred anklor of fix-CAI group, 2.7 (1.2) run in the marked newlved anklor of fix-counted group, and 2.8 (1.3) run in the marked surfaces of the counted group.	The take position in the CA1 arisks was significantly more anterior from that in the satistic dead analys (P = 0.03) and the rankbol involved ankles of the centrel group (P < 0.01).
Foot posture	Beldwin 2017 ²⁶	To invovigate the prevalence and correlates of perceived antick instability in a healthy population.	Case—control study	CAI group: 207 (bilineral unido invahility) control group: 608 (without askle instability)	Original criteris based on perceived ankle instability (CAIT sease <25).	CAIT score, CAIT-Youth score, feet alignment (FPL th, lower limb alignment, ander dentification ROM, ander planter flexion ROM, ander dentification strength, ander planter flexion strength, and ander planter flexion strength, and ander planter flexion-dentification ratio.	The main (SD) FFH-6 scores were 3.4 (2.3) in the CAI group and 3.3 (2.5) in the central group.	No significant difference between the CAI and control groups ($P=0.763$).
	Fraer 2020 ²⁷	To is esseligate the first postage and treephology, making-protein gives motion and pluy, strength, and dynamic balance in recruitmently active young addits with such without a history of a LAS, open, and CAL.	Case-control study	CSA group, 50 (5 mm., 15 women) capler group, 21 (6 mm., 12 women) LAS group, 17 (5 mm.) 9 cmmn) Houlity greep; 22 (9 mm., 13 women)	Origad critiss boot on pre-two stakk syntax and provised aside statistics. (LAS 2.12 resets prior to the today, MFAL2 10, TAAMS-AUC 50, and TAAM Span 50).	FPF4, resphologic receives (3 AIII with hadragineth fleichblysfor middly magatalet. (Not and adds post resides, year play, I garnestee insidences, flor and adds receipts, and dynamic hadron.	The near CD/1714 acres were \$4.0.5 in the CAI group, $3.6.14$ in the core group, $2.5.14$ in the LAS group, and $4.2.0$ group, $3.6.14$ in the core group, $2.5.03$ in the LAS group, and $4.2.0$ group in the core of group, $2.5.04$ is the LAS group, and $2.7.11$ is the decreated group group, 2.0 (10%) when the LAS group, and $2.7.11$ is the decreated group and 2.0 in CD/18 in the LAS group, and $2.7.11$ in the LAS group, and 2.0 in the decreated group and 2.0 in the CAI group, 3.0 in the CAI group, 3.0 in the CAI group, 3.0 in the LAS group, and 2.0 in the CAI group, 3.0 in the LAS group, and 2.0 in the CAI group, 3.0 in the LAS group, and 3.0 in the CAI group, 3.0 in the LAS group, and 3.0 in	. There were no significant differences in PPI-6 and morphologic measures.
	Kobayashi 2020 ²⁸	To evaluate the correlation between frost such height and chronic untile instability in female collegiste oblistes.	Case-control study	CA1 group: 10 women (12 feet) caper group: 55 women (176 feet)	Based on International Ankle Consortium criteria (a previous biotoxy of multiple ankle sprain and giving way, CAIT score <25).	AHI	The mean (SD) AHI were 0.36 (0.03) in the CAI group and 0.36 (0.02) in the coper group.	No significant difference between the CAI and coper groups (P = 0.85).
	Larses 1990 ³⁴	To evaluate the correlation between foot deformities and chronic lateral ankle instability.	Caso-control study	CAI group: 95 (49 men, 46 women) omirel group: 34 (13 men, 21 women)	Original criteris based on provious ankle speals and functional disability (increased take tiking of 6 degrees or more analyst anuation rotational take deplacement).	Foot deferring by standardized measurements on radiographs.	The mean differences in the blocalcaneal, coloured, belomestates of angle, and tersol index between the CAI and control groups were $20^\circ, 15^\circ, 54^\circ, and 5.7$.	Higher fast orders and a greater frequency of covas foot deformity were observed in the CA1 group (P \leq 0.04).
	Lee 2020 ³¹	To determine the prevalence of subfic carus foot in patients who underwent latend under figureent requires CAL.	e Case-control study	CAI group; 116 (58 mm, 58 woman) control group; 105 (42 mm, 45 woman)	Undergoing Intent table ligament record traction.	colorned pitch $sugle, Many \times sugle, difference in height between the first and differentiated bases, fibrile positives.$	The some (31) independ problemgie very $(31,7)$ in the CAI group and $(21,8)$ of (31) in the CAI group $(31,8)$ of (31) in the CAI group $(31,8)$ in the CAI group $(31$	SCF was not a significant risk factor for CAL
	Linux 2019 *	To analyze hindfoot alignment in potents with CAI using weight-housing costs boarn computed tensography.	reirospective cohort study	CAI group; 34 (20 men. 14 weesen) Other group; 155 (54 men. 101 weesen)	Original orienis-based on previous onlike spains and perceived onlice instability (Al Ison I reported spaceds of midd' giring-rowy' in the previous formetts, complaining of midde transhility, with at least I, price initial ankle spains requiring active transment).	feet and arkle office, valuesed offset, hindfoot onglo	The most (SD) freet and adder offset wave 2.2 (5.4) in the CA1 group and 2.6 (4.7) in the cost all gauge in the cost all gauge 1.6 (4.8) in the CA1 group and 6.7 (5.8) in the CA1 group and 6.7 (5.8) in the CA1 group and 6.7 (6.8) in the CA1 group and 10.6 (16.6) in the excessed group.	
	Van Bergeyk 2002 33	To determine radiological differences with respect to hindfoot verse/valgas oligeneess.	Case—control study	CAI group: 14 anklos control group: 14 ankles	Original criteria based on previous ankle sprain and functional disability (a previous history of multiple unitated ankle sprains or insuffility with symptom ongoing for at least six membs).	Axial plane: take tendeschillo negle (TEA); take-islamad negle (TEA); calcanso- nahod negle (CCA); and calcansal mentaned negle (CMA). Cerend plane: mobile calcansal versa negle (MCVA); certral calcansal varus negle (CCVA); sebillor vertrall negle (SVA); and nelse vertrall negle (AVA).	The mean (SD) values of TTA, TCA, CCA, CMA, MCVA, CCVA, SVA, and AVA went 150 (60), 3.5 (44), 1116 (37), 3.0 (4.3), 93.0 (4.4), 93.8 (1.2), 85.7 (104), 409.8 (1.5) in TCA (100), 400.8 (1.5) in TCA (10	. No significant difference between the CA1 and control groups (F $>$ 0.68).

Table 2 Quality assessment of the included studies

Studies ($n = 16$)	Criteria																
	1	2	3	5	6	7	10	11	12	15	16	18	20	21	22	25	Total
Baldwin 2017 [26]	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0	11
Berkowitz 2004 [13]	1	1	1	0	1	0	0	0	0	0	1	1	1	1	1	0	9
Caputo 2009 [6]	1	1	1	0	1	0	0	0	0	0	1	0	1	0	0	0	6
Fraser 2020 [27]	1	1	1	1	1	1	0	0	0	0	1	1	1	1	0	0	11
Hubbard 2006 [14]	1	1	1	0	1	0	1	0	0	1	1	1	1	1	0	0	10
Hubbard 2007 [28]	1	1	1	0	1	1	1	0	0	1	1	0	1	1	0	0	10
Kobayashi 2014 [15]	1	1	1	0	1	1	0	0	0	0	1	0	1	0	0	0	7
Kobayashi 2020 [29]	1	1	1	2	1	0	1	0	0	0	1	1	1	1	1	0	12
Larsen 1990 [30]	0	1	0	0	1	1	1	0	0	0	1	0	1	0	0	0	6
Lee 2020 [31]	1	1	1	1	1	1	1	0	0	0	1	0	1	1	1	0	11
Li 2017 [16]	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0	0	10
Lintz 2019 [8]	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	13
Magerkurth 2010 [32]	1	1	1	0	1	1	0	0	0	1	1	1	1	0	0	0	9
Van Bergeyk 2002 [33]	1	1	1	0	1	1	0	0	0	1	1	1	1	0	0	0	9
Wikstrom 2010a [34]	1	1	1	0	1	1	0	0	0	1	1	0	1	1	0	0	9
Wikstrom 2010b [35]	1	1	1	0	1	1	0	0	0	1	1	0	1	1	0	0	12
Mean score																	9.69 (57.0%

on sagittal plane radiographs [14, 28, 35], and one study used a three-dimensional (3D) bone model based on CT images [15]. The outcomes measured in these studies were the anterior/posterior and medial/lateral displacement of the fibula.

The two studies involving analysis of the axial plane found the lateral malleolus of the ankle to be significantly posterior in the subjects with CAI [13, 16]. Mean AMI was 11.06–17 degrees in the CAI group and 7.89–9 degrees in the control group [13, 16]. In contrast, of the three analyses using sagittal plane data, one described the lateral malleolus as significantly anterior in the subjects with CAI (mean difference from the control group, 1.8 mm) [14], whereas the others did not detect any significant difference [28, 35]. The 3D analysis did not find a significant difference in anterior/posterior position between the CAI ankles and the contralateral healthy ankles [15]. However, this analysis reported a significant lateral displacement of the fibula (the distal 10 cm of the fibula length) in the CAI ankles compared with the contralateral ankles (Table 1) [15]. The certainty of evidence of fibular anterior/posterior translation could not be determined, because the results were inconsistent. The certainty of evidence for fibular lateral/medial translation was very low (downgraded for bias and imprecision).

Talar positioning

Four studies including 139 patients (34.8 patients per study) investigated alignment of the talus in CAI [6, 16, 32, 34]. The methodological quality of all papers was low. Two studies recruited patients undergoing lateral ligament reconstruction surgery (only preoperative values were included as results) [6, 16], whereas the other two were based on functional disability, such as recurrent ankle sprains or subjective instability [32, 34]. One study measured talus alignment using a 2D analysis in the axial plane based on MRI images [16], two studies used 2D analysis based on sagittal plane radiographs [32, 34], and one study used a 3D-to-2D registration technique [6]. The measured outcomes were anterior/posterior translation and internal/external rotation of the talus.

The four studies reported consistent results. Regardless of the measurement method and whether or not the ankle was weight bearing, the talus of CAI ankles showed significant anterior displacement (0.9–1.0 mm) and internal rotation (3.85–5.7 degrees) compared with healthy ankles (Table 1) [6, 16, 32, 34]. The certainty of evidence of these results was low.

Foot posture

Seven studies including 494 patients (70.6 patients per study) investigated foot posture in CAI [8, 26, 27, 29–31, 33]. The methodological quality of one paper was high,

with the remaining six showing moderate or low quality. One study recruited patients with CAI who were undergoing lateral ligament reconstruction surgery (only preoperative values were included as results) [31], three of these recruited CAI subjects based on functional disability such as recurrent ankle sprains or subjective instability [8, 30, 33], and the others selected subjects according to scores with the Cumberland Ankle Instability Tool [26, 29] or Identification of Functional Ankle Instability and Foot and Ankle Ability Measure [27]. Two studies measured foot posture using 2D analysis in the frontal/ axial plane based on CT images [8, 33], and the other two studies used a 2D analysis of sagittal plane radiographs [30, 31]. In addition, two studies measured from the body surface, applying the Foot Posture Index (FPI-6), [26, 27] and the other two studies calculated arch height index (AHI) or foot mobility magnitude used instrumental measurements (e.g., from a 3D foot scanner) [27, 29]. The measured outcomes were midfoot/rearfoot alignment, including the foot arch height.

The study that used a 2D analysis of sagittal plane radiographs observed mean differences in talocalcaneal, calcaneal, and talometatarsal angles, and tarsal index between the CAI and control groups were 2.0°, 1.5°, 5.4°, and 5.7, respectively [30]. These results suggested a greater frequency of cavus foot deformity in the CAI group than in the control group. In addition, the study using CT images showed mean differences in foot and ankle offset, calcaneal offset, and hindfoot angle between the CAI and control groups of 4.8%, 9.9 mm, and 16.5°, respectively [8]. The authors concluded that hindfoot of CAI ankles was more varus than control ankles. However, the other five studies with image analyses and measurements from the body surface found no significant differences in foot posture between CAI and normal ankles (Table 1) [26, 27, 29, 31, 33]. The certainty of evidence for foot posture could not be determined, because the results were inconsistent.

Discussion

The aim of this systematic review was to clarify the relationships between CAI and abnormalities of foot posture and ankle alignment. The review included 16 studies that examined fibular or talus alignment or foot posture, retrieved through electronic screening. These indicated significant anterior displacement and internal rotation in the talus of CAI ankles compared with healthy ankles. However, there was no consensus regarding fibular alignment and foot posture.

The results for fibular anterior/posterior translation in CAI ankles differed across the six included studies. Differences in the reference bone may have been the main cause of this variation. Some studies referenced to the tibia and others to the talus, making it difficult

to compare findings across the studies. The 3D analysis found the fibulas of CAI ankles were in a significantly lateral position compared with those of the contralateral side [15]. The authors' explanation for this was that lateral displacement of the fibula widened the distal tibiofibular joint, affecting the mortise structure and that this was associated with excessive talar rotation [15]. Fibular repositioning tape is used to treat CAI; this has been shown to improve postural stability [36, 37]. The aim of this approach is to correct fibula alignment using a nonrigid and rigid tape applied from the distal aspect of the fibula, wrapped around the posterior aspect of the leg to apply superoposterior mobilization force to the distal fibula, equal to a Grade IV joint mobilization [36, 37]. However, the findings of the present review showed that the fibulas of CAI ankles may not necessarily be displaced anteriorly, so other interventions, including different taping methods, should also be investigated. Meanwhile, the anterior tibiofibular ligament injury may be involved in some patients with lateral ankle sprains, and this ligament dysfunction may contribute to abnormalities of fibular alignment [15]. In addition, the anterior talofibular ligament and the calcaneofibular ligament was connected at the anterior tip of the lateral malleolus, [38, 39] and repair or reconstruction of these ligaments for CAI may contribute to the improvement of fibular alignment. However, the indications for surgery in patients with CAI are determined based on pain and instability, and the degree of fibular deviation to use as a criterion for surgery remains unclear [40]. However, reliable 3D imaging evaluation is important because abnormal alignment is likely to be associated with functional impairment. In addition, we believe that the tibia should be the criterion when evaluating fibular alignment because the results of this review suggest that CAI causes abnormal anterior displacement and internal rotation in the talus.

The studies included in this systematic review consistently showed significant anterior displacement and internal rotation of the talus of CAI ankles. The main cause for this is thought to be damage to a lateral ankle ligament (such as the anterior talofibular ligament) caused by repeated lateral ankle sprains [6]. These abnormalities can cause limited range of motion, pain, and cartilage damage, which may be associated with the development of osteoarthritis in the future [4, 41]. Wainright et al.[19] have reported that surgical repair of the anterior talofibular ligament in CAI decreased anterior translation and internal rotation of the talus, therefore, surgical repair of the lateral ankle ligament appears to be effective in improving talar alignment. In addition, joint mobilization to improve talar posterior gliding is performed as a treatment for CAI, and has been shown to improve the range of ankle dorsiflexion, ankle plantar-flexion angle at initial contact during a single-leg drop landing, and dynamic postural stability as assessed by posteromedial distance in the star excursion balance test [42, 43]. It is thought that increasing talar posterior gliding improves the anterior displacement of the talus in CAI ankles [44]. In contrast, no effective conservative treatment such as taping or semi-rigid brace for increasing internal rotation of the talus has been reported; this needs further study. Furthermore, no conclusions have been reached regarding the most effective technique for improving talar alignment for preventing osteoarthritis [5, 45].

There was no consensus among the seven studies in this review regarding the characteristics of foot posture in individuals with CAI. In the study by Larsen et al. [30], the foot arches of the CAI group were higher than those of the healthy group, and Lintz et al.[8] concluded that CAI ankles was more varus than control ankles. These two studies that used 2D image analysis indicated abnormalities in CAI, but no foot malalignment in CAI was observed in body surface evaluation studies such as AHI, FPI-6, and foot mobility magnitude [26, 27, 29]. This difference may depend on the measurement methods and the criteria of CAI subjects. Although some studies have examined the relationship between foot alignment and ankle sprain, they came to no conclusion [46]. Further studies are needed on the relevance of foot posture abnormalities for CAI using more reliable instrumented measures or 3D image analysis.

In CAI, abnormal alignment of the talus may contribute to abnormal arthrokinematics and cartilage loading pattern of the talocrural joint, so assessment of talar alignment using reliable modality is useful in clinical practice. As no consensus has been reached regarding the abnormalities of fibular alignment in CAI, intervention methods must be considered according to the specific alignment abnormality in each case. The tibia may also represent the optimal reference for reliable assessment of fibular alignment. In addition, no clear relationship was apparent between foot posture and CAI from the findings of this systematic review. However, since abnormalities of foot posture are suspected to be associated with various clinical dysfunctions, accumulation of further results using reliable methods is important.

This systematic review included 16 retrospective cohort, case—control or cross-sectional studies. Although these provided results regarding the relationship between several aspects of foot or ankle alignment and CAI, the quality of almost included studies was not high, so the evidence underpinning the findings of this systematic review is not strong. In addition, differences in CAI selection criteria among the studies may have influenced the results. For example, some studies included patients with mechanical instability of the ankle joint who resisted

conservative treatment, while other studies used a history of ankle sprain and perceived instability as inclusion criteria and did not include the presence or absence of mechanical instability. In addition to mechanical impairments (e.g., arthrokinematics restrictions) and perceptual impairments (e.g., perceived instability), neurophysiological problems were also associated with the pathogenesis of CAI [4]. Future studies should therefore refer to the selection criteria of the International Ankle Consortium to consider coper's subjects as well [2]. Also, because it is likely that ligamentous dysfunction would affect alignment of the foot and ankle, the presence or absence of mechanical instability should be clarified for each subject. Although foot posture is considered to be influenced by biological sex [47], the present study was unable to consider the effects of sex. Finally, the differences in measurement methods among the studies made it difficult to integrate the results through a meta-analysis. The development of a simple, high-precision measurement method for physicians and therapists is needed.

Conclusion

The aim of this systematic review was to clarify the relevance for CAI of foot and ankle alignment. The review identified that there was significant anterior displacement and internal rotation in the talus of CAI ankles compared with healthy ankles, but there was no consensus on the characteristics of fibular and foot alignment. In addition, the quality of the studies that investigated foot and ankle alignment was not high. Future studies are needed to clarify the foot and ankle malalignments characteristic of CAI, as well as related ligament injuries, using unified selection criteria. This should facilitate the development of efficient interventions.

Abbreviations

CAI: Chronic ankle instability; 2D: Two-dimensional; 3D: Three-dimensional; CT: Computed tomography; MRI: Magnetic resonance imaging; FPI: Foot Posture Index; AHI: Arch height index; GRADE: Grading of Recommendations Assessment, Development and Evaluation.

Supplementary Information

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Additional file 1.

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Authors' contributions

Takumi Kobayashi; design of the work, acquisition, analysis, drafted and revised the work. Yuta Koshino; design of the work, acquisition, analysis, drafted and revised the work. Takahiro Miki; acquisition, analysis.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

¹Department of Rehabilitation, Faculty of Health Science, Hokkaido Chitose College of Rehabilitation, 2-10 Satomi, Chitose, Hokkaido 066-0055, Japan. ²Rehabilitation Center, NTT Medical Center Sapporo, Sapporo, Hokkaido, Japan. ³Department of Rehabilitation, Sapporo Maruyama Orthopaedic Hospital, Sapporo, Hokkaido, Japan.

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